WATER-YIELD AND WATER-QUALITY STUDY OF WALNUT CREEK AND WOMAN CREEK WATERSHEDS ROCKY FLATS PLANT SITE

Task 4
As a Part of
Zero-Offsite Water-Discharge Study
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DISCLAIMER

TABLE OF CONTENTS

TABLES

FIGURES

TABLE OF CONTENTS
continued

APPENDICES

WATER-YIELD AND WATER-QUALITY STUDY OF WALNUT CREEK AND WOMAN CREEK WATERSHEDS
Rocky Flats Plant Site

EXECUTIVE SUMMARY

This is a report of one of several studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE) (ASI, 1990a). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review."

Specifically, this report addresses two important issues related to impacts of zero discharge of surface waters from the RFP: (1) quantitative injury to existing downstream water rights; and (2) loadings of selected water-quality constituents to Standley Lake from Woman Creek and to Great Western Reservoir from Walnut Creek (ASI, 1990b). Because implementation of the concept of zero discharge of runoff from all or part of the RFP may constitute injury to downstream water rights, this hydrologic study of the annual/monthly water yield of the Walnut Creek and Woman Creek watersheds forms a basis for assessing the need for replacement of water to those water rights which may possibly be injured. In addition, this study has identified and quantified the water-quality loads for selected indicator constituents from the Woman Creek and Walnut Creek segments at the RFP.

Two studies (Water Rights - Task 14 and Augmentation Plan - Task 28) which are subordinate to the Zero-Offsite Water-Discharge Plan will rely on the results presented in this report to address water rights issues related to Zero-Offsite Water-Discharge.

Water Yield

In this report, the usage of the terms Walnut Creek, North Walnut Creek, and South Walnut Creek refer to the following stream reaches: the term Walnut Creek is used for the stream reach downstream from the confluence of North and South Walnut Creeks. North Walnut Creek and South Walnut Creek are the terms used in reference to locations upstream from their confluence.

The U.S. Geological Survey (USGS) operated continuous stream gages on Woman Creek, North Walnut Creek (referred to as Walnut Creek by the USGS), and South Walnut Creek for varying periods of time between 1972 and 1975. However, these data were collected for an insufficient period of time, at these sites, to allow direct determination of long-term annual or monthly water yield from the RFP watersheds and as a result of local data insufficiencies a regional analysis was undertaken. Additionally, the natural yields of the watersheds were augmented by water which had been diverted from Coal Creek to Great Western Reservoir and Standley Lake through ditches feeding Woman and Walnut Creeks, and RFP treatment plants and processes which have discharged water into RFP basins and reservoirs. Records of the amounts of water thus diverted or discharged are available through the State Engineer or RFP records, but in some instances they are incomplete. For example, for some years information is available in the State Engineer's files that water was diverted, but neither the quantity nor the timing of the diversions are specified.

The annual-yield values needed to assess potential injury to downstream water users, should a plan of zero discharge from RFP be implemented, are the amounts of water, on average, which would be yielded from RFP watersheds under natural conditions. Because on-site data are not available to permit direct calculation of annual or monthly yield from RFP streams, a regional analysis was undertaken. Seasonal (April-through-October) yield from 28 USGS rainfall-runoff gaging stations with approximately 10 years of record was related to physical basin characteristics including drainage area, mean annual precipitation, elevation and relief factors, and channel and watershed slope. Results of a multiple-regression analysis are that seasonal yield, adjusted to long-term average annual yield, best relates to effective drainage area in the form of the following equation:

$$Q_a = 13.986 \, EDA^{0.7574}$$

where Q_a = Long-term average Annual yield, in acre-feet, and
EDA = Effective drainage area, in square miles.

Long-term average annual yield estimates for Woman Creek at Indiana Avenue (RFP surface-water sampling sites SW-1 and SW-2), Walnut Creek at Indiana Avenue (RFP site SW-3), and North and South Walnut Creeks at their confluence (RFP sites SW-16 and SW-25, respectively) are given in the following table.

Estimates of Long-Term Average Annual Yield

STREAM	DRAINAGE AREA (sq mi)	ANNUAL YIELD (ac-ft)
Woman Creek	3.0	32.1
North Walnut Creek	1.9	22.7
South Walnut Creek	0.6	9.5
Walnut Creek	3.3	34.5

During any ten-year period, annual yield is predicted to range from zero to approximately four times the long-term average annual yield.

The distribution of annual yield on a monthly basis was estimated by examining the distribution of annual runoff at several long-term USGS gaging stations, and by examining the distribution of runoff at the 28 rainfall-runoff gaging stations. Monthly yield, as a percent of annual yield (AY), can be estimated from the distribution given below. Estimates of long-term average monthly yield, in acre-feet, for the four RFP sites previously described are also given below.

Estimates of Long-Term Monthly Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% AY	1	1	4	5	16	24	20	20	6	1	1	1
Woman C.	0.3	0.3	1.3	1.6	51.	7.7	6.4	6.4	1.9	0.3	0.3	0.3
Walnut C.	0.3	0.3	1.4	1.7	5.5	8.3	6.9	6.9	2.1	0.3	0.3	0.3
S. Walnut C.	0.1	0.1	0.4	0.5	1.5	2.3	1.9	1.9	0.6	0.1	0.1	0.1
N. Walnut C.	0.2	0.2	0.9	1.1	3.6	5.5	4.5	4.5	1.4	0.2	0.2	0.2

Annual and monthly yields calculated from the above equation and distribution are estimates of long-term averages, and are not usable to predict yields for a specific year or a month in a specific year. Also, they allow estimation of annual and monthly yield for natural-flow conditions. They do not allow consideration of potentially increased runoff from impervious areas, such as buildings and parking lots, nor do they consider reduced runoff as a result of storage of water in reservoirs and subsequent evaporation.

Water Quality

Surface-water samples have been collected from numerous sites on the RFP in 1989 and 1990 (Woodward-Clyde, 1990). It is recommended that a long-term surface-water sampling program be continued at the RFP. Analyses of water collected from sites SW-1 (Woman Creek at Indiana Avenue), SW-3 (Walnut Creek at Indiana Avenue), SW-16 (North Walnut Creek between reservoirs A-3 and A-4), and SW-25 (South Walnut Creek between reservoirs B-4 and B-5) were examined and used for water-quality loading analysis. Data from several other surface-water quality sampling sites were also presented for comparison purposes. Annual loading (constituent concentration times water volume) of chemical and radiochemical constituents, total dissolved solids (TDS), beryllium, copper, lead, americium-241, plutonium-239, various uranium isotopes, gross alpha and beta, and tritium, was estimated at surface-water sampling sites SW-1, SW-3, SW-16 and SW-25. Representative water-quality constituent concentrations were estimated from available data and multiplied by estimated average annual water yield, determined by the analysis discussed previously. Results of the annual-loading analysis for Woman and Walnut Creeks at Indiana Avenue are presented in the body of the main report.

In dry years, no naturally-occurring runoff is predicted for the Woman Creek and Walnut Creek watersheds, so loading to these streams from the RFP is not expected. Water diverted from Coal Creek or other upstream sources through the RFP will transport chemical and radiochemical loads, based primarily on the quality of the water diverted. Once every ten years or so, a wet year, during which approximately four times the annual yield is predicted to run off, will occur. If a worst-case assumption is made that chemical and radiochemical constituent concentrations will be approximately equal to those observed at the RFP "SW" sites, then the chemical and radiochemical loads will also increase by a factor of four times. The estimated wet-year loads are also detailed in the body of the main report.

WATER-YIELD AND WATER-QUALITY STUDY OF
WALNUT CREEK AND WOMAN CREEK WATERSHEDS
Rocky Flats Plant Site

1.0 INTRODUCTION

This is a report of one of several studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE) (ASI, 1990a). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review." Specifically, this report addresses two important issues related to impacts of zero discharge of surface waters from the RFP: (1) possible quantitative injury to existing downstream water rights; and (2) loadings of selected water-quality constituents to Standley Lake from Woman Creek and to Great Western Reservoir from Walnut Creek (ASI, 1990b). Because implementation of the concept of zero discharge of runoff from all or part of the RFP may constitute injury to downstream water rights, this hydrologic study of the annual/monthly water yield of the Walnut Creek and Woman Creek watersheds forms a basis for assessing the need for replacement of water to those water rights which may possibly be injured. In addition, this study has identified and quantified the water-quality loads for selected indicator constituents from the Woman Creek and Walnut Creek segments at the RFP.

No new field-data collection efforts were conducted during the course of this study. Rather, this study has relied on data and information from the RFP surface-water data-collection program and historic data available from the U.S. Geological Survey (USGS), the Colorado State Engineer and the RFP. Important words and terms used in this report are defined in Appendix A, "Definition of Terms."

2.0 WATER-YIELD ANALYSIS

2.1 RFP Drainage-System Description

The major drainage systems in the RFP area are Walnut Creek, North Walnut Creek, South Walnut Creek and Woman Creek. In this report, the use of the terms Walnut Creek, North Walnut Creek and South Walnut Creek refer to the following stream reaches: the term Walnut Creek is used for the stream reach downstream from the confluence of North and South Walnut Creeks. North Walnut Creek and South Walnut Creek are the terms used in reference to locations upstream from their confluence. These streams are ephemeral (Hurr, 1976); that is, they flow primarily in response to runoff from precipitation events. At times, these streams have carried water discharged from RFP process or treatment facilities and continue to carry water diverted from other streams (primarily Coal Creek) to Standley Lake and Great Western Reservoir (Figure 1).

North Walnut Creek and South Walnut Creek drain the central and northern areas of the RFP, and Woman Creek drains the southern areas (Figure 1). South Walnut Creek and North Walnut Creek join to form Walnut Creek. Their confluence is downstream from the RFP and upstream from Great Western Reservoir, into which Walnut Creek flows. Great Western Reservoir supplies water to the City of Broomfield. Woman Creek flows easterly across the southern portion of the RFP into Standley Lake, which provides irrigation storage and municipal water for the cities of Westminster, Northglenn, and Thornton (Figures 1 and 2).

Several ditches convey water through or near the RFP. Located west of the RFP, the South Boulder Diversion Canal carries water southward from South Boulder Creek to Ralston Reservoir, which is south of the RFP and serves as a water supply to Denver. The water supply for the RFP is also obtained from the South Boulder Diversion Canal and Ralston Reservoir. The Upper Church, McKay (also known as Zang) and Kinnear Ditch and Reservoir Co. ditches divert water from Coal Creek. The Upper Church Ditch supplies water to Upper Church Lake (located northeast of the RFP) and Great Western Reservoir. McKay Ditch conveys water to Great Western Reservoir via Walnut Creek, and the Kinnear Ditch routes water to Standley Lake through Woman Creek. The Smart 2 Ditch diverts water from Rocky Flats Lake, located southwest of the RFP, into a Woman Creek tributary. The South Interceptor Ditch collects runoff from the central RFP area, preventing it from entering the Kinnear Ditch and Woman Creek, and routes that runoff to an off-channel impoundment, Pond C-2. Runoff from the upper (western) reaches of North Walnut Creek is collected and diverted through the West Interceptor ditch to McKay Ditch, which rejoins Walnut Creek downstream from the RFP (Figures 1 and 2).

In addition to naturally occurring runoff, the flow of Woman Creek has been augmented by diversions from Coal Creek, leakage and spillage from South Boulder Diversion Canal and backwash from the RFP's water-supply filter system (Hurr, 1976). After June 1975, the backwash was not discharged into Woman Creek but was recycled. Prior to late 1974, effluent from RFP's sanitary-sewage treatment plant (STP) was released into South Walnut Creek. Since that time, the policy has been to retain all process wastewater on the plant site and lose it by evaporation.

Several on-channel reservoirs exist on North Walnut Creek, South Walnut Creek and Woman Creek. Ponds A-1 through A-4 are on North Walnut Creek, Ponds B-1 through B-5 are on South Walnut Creek, and Pond C-1 is on Woman Creek. Pond C-2 is off-channel but is in the Woman Creek watershed downstream from Pond C-1 (Figure 1). Table 1 gives information for the RFP reservoirs (U.S. Army Corps of Engineers, 1989).

2.2 Available Historic Data

2.2.1 U.S. Geological Survey, Walnut Creek and Woman Creek Watersheds

The U.S. Geological Survey (USGS) operated continuous stream-gaging stations on North Walnut Creek, South Walnut Creek and Woman Creek during the early to mid 1970's to measure outflow from the plant area (Figure 1). Table 2 summarizes USGS gaging station information (Hurr, 1976 and USGS, 1976). Two stations were operated on Woman Creek; Woman Creek at RFP and Woman Creek near Plainview. After July 1973, the Woman Creek at RFP stream gage was discontinued and moved upstream from Pond C-1 to the stream-gaging site named Woman Creek near Plainview. Appendix B, "USGS Stream-Gaging Data for RFP Sites," contains stream-gaging data for the Woman Creek, North Walnut Creek (referred to as Walnut Creek by the USGS) and South Walnut Creek sites (USGS, 1976).

2.2.2 Colorado Division of Water Resources, State Engineer

The Office of the State Engineer maintains historical records of water diversions through individual ditches; records collected by their staff and Water Commissioners. Appendix C, "State Engineer Ditch Diversion Records," contains a summary of diversion records obtained through the State Engineer's Office for the Upper Church, McKay (also known as Zang) and Kinnear Ditches. Records are not available for Smart 2 Ditch. In some instances, the available State Engineer's records were incomplete. For example, statements were made in the records that diversions to Standley Lake or Great Western Reservoir through a specific ditch were made.

Table 1
RFP Pond Information

WATERSHED	POND NAME	DAM HEIGHT (ft)	MAXIMUM POOL CAPACITY (ac-ft)	SPILLWAY CREST CAPACITY (ac-ft)
North Walnut Creek	A-1	17	12.3	4.9
	A-2	29	31.4	19.0
	A-3	37.5	76.0	43.0
	A-4	46	153.5	94.0
South Walnut Creek	B-1	16	8.0	3.1
	B-2	26	14.9	7.5
	B-3	18	6.0	2.2
	B-4	19	5.7	1.8
	B-5	54	120.0	79.3
Woman Creek	C-1	15	17.1	5.9
	C-2	35.5	173.5	70.7
North Walnut	Landfill	40.5	43.5	28.0

Table 2
USGS Stream-Gaging Stations on Walnut and Woman Creek Watersheds

USGS NUMBER AND NAME	PERIOD OF RECORD	RAINAGE AREA (sq mi)	GAGE ELEVATION (ft above MSL)
06720690 Woman C. nr Plainview	Jul 1973-Oct 1974	1.77	5,855
06720700 Woman C. at RFP	Aug 1972-May 1973	2.10	5,755
06720780 Walnut C. at RFP	Jun 1972-Oct 1974	1.24	5,760
06720790 S. Walnut C. at RFP	Jul 1972-Oct 1974	0.46	5,800

However, quantification of the amount of water diverted was not given. In other instances, quantity of diversion was specified, but the timing of delivery was not.

2.3 Water-Yield Analysis

2.3.1 Annual Yield

Because the duration of stream-gaging records for Woman Creek, North Walnut Creek and South Walnut Creek were too short for adequate analysis of annual or monthly yield, a different approach was taken. Stream-gaging records for sites in eastern Colorado comparable to the RFP, based on criteria discussed below, with longer periods of record were obtained and examined to evaluate whether relationships between annual and monthly yield and watershed characteristics could be developed.

First, stream-gaging records from long-term USGS stations were examined. The first selection criterion was that amount of water diverted into or out of the watershed upstream from the gage be minimal. With irrigation and inter-basin diversion being so prevalent in Colorado, numerous stations were eliminated from further consideration based on this criterion. A second criterion was that the stream-gaging site should be located in a topographic and climatologic region similar to the RFP. Again, numerous stream-gaging sites considered for this study analysis were eliminated from consideration, because they were located in mountainous areas where water yield from snowmelt is a primary factor. At the RFP and similar areas, the primary source of runoff is from rain storms. Most snow that falls in areas similar to the RFP melts and evaporates or infiltrates into the ground. Only rarely does melting snow cause a significant runoff event.

Another important data-selection criterion was watershed drainage area. Watershed areas, upstream from Indiana Avenue for Walnut and Woman Creeks and upstream from their confluence for North Walnut and South Walnut Creeks, are 0.6 to 3.3 square miles (mi^2), respectively (Figure 1). Some long-term stream-gaging records were collected at sites with several hundred square miles of drainage area which disqualified them from further consideration. Often, ground-water discharge becomes a significant contribution to annual and monthly yield in larger watersheds. For small basins similar in size to the RFP watersheds, ground-water contribution to annual flow is generally small or zero, and flow generally occurs only in response to a precipitation event.

After consideration of the record-selection criteria discussed above, only a few long-term records were judged suitable for regional analysis. However, the USGS conducted a data-collection program between about 1969 and 1979 wherein rainfall and runoff data were collected at numerous sites on basins in eastern Colorado, ranging from 0.26 to 22.6 mi^2 in effective drainage area. These stations were operated continuously between April and October each year during the program. Rainfall-runoff data collected during the USGS program were published in Ducret and Hodges (1972, 1975) and Cochran and others (1979, 1983).

These rainfall-runoff data were examined, as a result of the current study, and 28 streamflow data-collection sites were selected for annual-yield analysis, based on adequacy of period of record and adequacy of number of runoff events observed (Figure 3). During the course of the current study, it was found that gaging stations with fewer than five years of record during which runoff events were observed generally were outliers in the relationships developed between annual yield and basin characteristics. Therefore, those sites with fewer than five years of non-zero runoff records, which appear to be outliers, were eliminated from the analysis. Another site, for which sufficient data were available, was also found to be an outlier and was eliminated from the analysis. The sites used for analysis are presented in Appendix D, "Water-Yield Analysis Data", Table D-1, along with selected basin characteristics. The basin characteristics were obtained from Livingston and Minges (1987). Appendix D, Table D-2 lists data used in the annual-yield analysis for each gaging station.

Livingston and Minges (1987) developed a regional regression relationship whereby runoff volume could be calculated as a function of flood-peak discharge. That relationship was as follows:

$$V = 0.222\, Q_p^{\,0.866} \qquad (1)$$

where: V = flood volume, in acre-feet (ac-ft), and
Q_p = peak flood discharge, in cubic feet per second (cfs).

For each runoff event observed at the 28 gaging stations, the flood volume was calculated. Volumes were summed and seasonal (April-through-October) totals for each year were computed.

Although a large percentage of annual-runoff volume in small ephemeral streams occurs in response to rainfall events, a small percentage of annual runoff may occur as a result of snowmelt or from ground-water discharge through springs. Therefore, an analysis was performed to estimate the amount of runoff volume that can be expected to occur during the November-through-March period. Statistical summaries of several long-term stream-gaging stations were examined (Petsch, 1979). Stream-gaging stations used in this analysis are listed on Table D-3 of Appendix D, and locations are shown on Figure 3. The volume of runoff, for the records examined, occurring between November and March, expressed as a percentage of annual runoff, ranged from 4 percent to 20 percent, with an average of approximately 8 percent and a median value of 6 percent.

Most of the gaging-station records used for the analysis to adjust seasonal yield were for watersheds considerably larger (15.1 to 302 square miles) than those at the RFP. However, they represent the best data available for this analysis and provide a means for a reasonable estimate of the seasonal yield.

Mean seasonal (April-through-October) runoff volume for the 28 rainfall-runoff stations analyzed was increased by 8 percent (the average November-through-March percentage of annual runoff for the larger stream-gaging sites) and used as an approximation of mean annual runoff volume (yield). A step-wise multiple regression analysis then was performed so that a relationship between annual yield and basin physical characteristics could be developed. Basin characteristics considered were the following: effective drainage area, stream-gage elevation factor, basin relief factor, channel slope, watershed slope and mean annual precipitation (Table D-1). It was found that transforming annual yield and basin-characteristic values to base-ten logarithms significantly improved the multiple-regression relationship fit.

A matrix of correlation coefficients for annual yield and all basin characteristics considered is presented in Appendix D, Table D-4. The best correlation between annual yield and any of the basin characteristics was with effective drainage area. The correlation coefficient for these two variables was 0.76. All other correlation coefficients for annual yield and individual basin characteristics were 0.4 or less. Several basin characteristics correlate well with each other. For example, relief factor and channel slope had a correlation coefficient of 0.89, and channel slope and watershed slope had a correlation coefficient of 0.73. The high correlation between certain basin characteristics is not unexpected. However, results of multiple-regression analyses can be biased when independent variables are highly correlated to each other. Therefore, after identifying related independent variables, subsequent step-wise analyses eliminated one of the related variables.

After review of the multiple-regression analyses, it was found that base-ten logarithm transformed effective drainage area, considered by itself, best relates to base-ten logarithm transformed annual yield for the 28 rainfall-runoff gaging stations used in this analysis. Figure 4 shows the log-log plot of annual yield versus effective drainage area and the calculated line of best fit. The regression equation developed is as follows:

$$Q_a = 13.986 \text{ EDA}^{0.7574} \qquad (2)$$

where Q_a = annual watershed yield, in ac-ft, and
EDA = effective drainage area, in mi^2.

The standard error of estimate for the preceding relationship was + 67 percent to - 40 percent, and the correlation coefficient was 0.76. According to Yevjevich (Colorado State University, Oral Communication, 1976), the degree of association, or correlation, of two hydrologic variables is judged significant when the correlation coefficient exceeds the absolute value of 0.70. At this value of the correlation coefficient, approximately 50 percent of the variance of the dependent variable is explained by the value of the independent variable.

The range of drainage areas of the watersheds used to develop equation (2) was 0.92 to 14.6 sq. mi. If the relationship is used for basins with drainage areas outside this range, the uncertainty of the resultant prediction is increased.

Based on equation (2), estimates of annual yield for Woman Creek at Indiana Avenue (RFP surface-water sampling sites SW-1 and SW-2), North Walnut Creek and South Walnut Creek at their confluence (RFP sites SW-16 and SW-25, respectively), and Walnut Creek at Indiana Avenue (RFP site SW-3) were calculated (Table 3).

Equation (2) was developed for natural watershed conditions and basins with little or no urban development and upstream storage. Therefore, the relationship can only be used to predict annual yield from natural-flow watersheds. Annual-yield values given for RFP streams are estimates of the amount of yearly runoff that would occur if no development affecting water yield had taken place. However, the RFP currently has significant amounts of impervious areas, such as buildings and parking lots. These impervious areas generally tend to increase total runoff by reducing subsurface infiltration. The quantity of increased annual yield at RFP as a result of development is not known. The RFP also has a significant amount of on-

Table 3
Estimates of Average Annual Yield

STREAM	DRAINAGE AREA (sq mi)	ANNUAL YIELD (ac-ft)
Woman Creek	3.0	32.1
North Walnut Creek	1.9	22.7
South Walnut Creek	0.6	9.5
Walnut Creek	3.3	34.5

channel storage in the form of the "A", "B" and "C" Series ponds. Much runoff impounded in these reservoirs is lost to evaporation, qualitatively counter-balancing the effects of development of impervious areas.

A comparison of estimates of annual yield for RFP streams given in Table 3 was made for the years in the early 1970's when USGS stream gages on the RFP were operational. Factors altering natural basin yield at that time include diversion of water from Coal Creek through ditches into the stream channels, release of sanitary sewage effluent and other RFP backwash or process water into the channels, and increased impervious area in the form of buildings and parking lots. Also, evaporation from reservoirs undoubtedly affected natural yield as observed at the stream-gaging sites. A summary of this comparison is shown in Table 4. Long-term average-annual values predicted for Woman, North Walnut and South Walnut Creeks, given in Table 4, are based on drainage areas at the USGS gage sites (Table 2). The net amount of runoff in Woman Creek attributable to natural basin runoff is not calculable for either of the 1973 or 1974 water years (October 1 - September 30) or parts thereof. Insufficient data are available regarding the amount of backwash water discharged from RFP's water-supply filter system, and data are not available from State Engineer records regarding the amount of water, or whether water was diverted at all into the Kinnear Ditch, through Woman Creek past the USGS gaging station and into Standley Lake (Figure 1).

In North Walnut Creek, for water year 1973, the runoff volume observed at the USGS stream gage (486 ac-ft) is considerably greater than that estimated by regression equation (2) as the long-term annual-average yield (16.5 ac-ft). State Engineer records do not indicate that any diversions were made from Coal Creek that would flow into North Walnut Creek past the USGS gage. Similarly, RFP records do not indicate that any plant effluent was directed to North Walnut Creek during that period of time. Unusually large runoff events occurring in April and May 1973, account for part of the disparity. Approximately 6.3 inches of precipitation were recorded at a USGS-operated precipitation gage located on Walnut Creek between April 18 and the end of May 1973, including a 2.52 inches one-day event on May 6 (Hurr, 1976).

The large runoff volume observed at the South Walnut Creek stream gage in 1973 also was undoubtedly affected by the unusually heavy precipitation during April and May of that year. During water year 1974, the amount of water discharged from the RFP's sanitary-sewage treatment plant nearly equalled the volume of water which flowed past the USGS gage. Therefore, the amount of naturally-occurring runoff observed at the USGS gage was judged to be very small. Loss of water due to evaporation from storage reservoirs

Table 4

Comparison of Estimated and Observed Annual Yields

STREAM	WATER YEAR	ANNUAL YIELD, ac-ft: USGS OBSERVED	ANNUAL YIELD, ac-ft: DITCH DIVERSIONS	ANNUAL YIELD, ac-ft: RFP DISCHARGE	ESTIMATED ANNUAL MEAN YIELD	ESTIMATED AVERAGE ANNUAL YIELD
Woman Ck.	1973	1,961*	0	NI	--	24.5
	1974	293@	NI	NI	--	21.6
N. Walnut Ck.	1973	486	0	--	486	16.5
	1974	--	0	--	--	16.5
S. Walnut Ck.	1973	417	N/A	222	195	7.8
	1974	145	N/A	144	1	7.8

Notes:

- * Observed yield at Woman Ck. at RFP (D.A. = 2.1 sq. mi.), August 1972 - May 1973.
- @ Observed yield at Woman Ck. near Plainview (D.A. = 1.77 sq. mi.), October 1973 - September 1974.
- NI No information available.
- N/A Not applicable.

probably accounts for some of the difference between observed-annual and estimated average-annual yield.

The conclusion is that, after reviewing a number of sources, insufficient data are available to adequately substantiate the regression equation presented herein. This is not unexpected, because annual yield of small streams typically varies significantly from year to year. Many of the rainfall-runoff gaging stations used in this analysis had annual yields which ranged from zero to several hundred acre-feet. Therefore, values estimated by equation (2) and given for RFP streams in Tables 3 and 4 are considered to be estimates of long-term average-annual yield from natural-flow watersheds, and would not serve as a good predictor of annual yield for a specific year.

At most of the 28 rainfall-runoff stations analyzed during this study, no flow was observed for one or more of the eight to eleven years of record. Table D-2, Appendix D, presents the range of adjusted annual mean volumes for the 28 stations. Therefore, it might reasonably be inferred that, for one or two years out of every ten, Walnut Creek, North Walnut Creek, South Walnut Creek and Woman Creek would have no naturally-occurring annual water yield.

As discussed previously, the annual yield ranged from zero to several hundred acre-feet at the 28 rainfall-runoff gaging stations. The maximum annual yield observed at each of the 28 gaging stations was, on the average, four (4) times greater than the mean adjusted annual yield. For the RFP streams, it is estimated that the annual yield might exceed the long-term average by a factor of four times approximately once every ten years.

2.3.2 Monthly Yield

An analysis similar to that performed for annual yield was attempted for monthly water yield. Average monthly yield for each month, April through October, for 28 rainfall-runoff gaging stations (see Table D-1, Appendix D) was estimated using a similar technique to that which had been used to estimate annual yield previously. Then a multiple regression analysis, whereby monthly yield was related to several basin characteristics, was performed. Results of this analysis were judged to be unsatisfactory. That is, no acceptable correlations between monthly yields and the basin characteristics were observed. Although relationships can probably be developed relating monthly yields and basin characteristics, the quantity of data available at the time of this report did not allow a quantitative formulation of those relationships.

In order to estimate long-term average monthly yield at the RFP, it was decided instead to develop a distribution of runoff for each month as a percent of long-term average annual yield. For each of the rainfall-runoff stations used in the analysis of annual yield, distribution of runoff by month was calculated. Table D-5, Appendix D lists monthly runoff as a percent of annual runoff for each of the 28 rainfall-runoff gaging stations. Again it was assumed, based on the previously described analysis, that an average of 8 per cent of annual yield for these basins occurs between November and March. Monthly-distribution percentages were averaged and compared with average monthly-distribution percentages calculated for the long-term gaging-station records used to formulate seasonal distributions (see Appendix D, Table D-5). The final rounded monthly-distribution percentages are presented in Table 5 and are also given in Table D-5, Appendix D. These values were estimated by comparing the average monthly-distribution percentages of the 28 rainfall-runoff station records and the average monthly-distribution percentages of the long-term gaging-station records. Table 5 also presents example estimated monthly yields, in ac-ft, for RFP streams calculated by applying monthly-distribution percentages to estimated annual yield of the respective streams which are given in Table 3.

Monthly precipitation records have been collected at the RFP for a 24-year period from 1953 through 1976. A comparison was made of the monthly distribution of observed precipitation at the RFP to the average monthly distribution of runoff at the long-term USGS gaging stations, and between RFP precipitation and the estimated monthly distribution of flow for RFP streams (Appendix D, Table D-5). The RFP precipitation distribution does not compare well with either the monthly distribution of runoff at the long-term USGS gaging stations or the estimated monthly distribution of streamflow at the RFP. The main reason for the poor comparison is that approximately 23 percent of annual precipitation at the RFP occurs from November through March, but an average of only 8 percent of annual runoff occurs during that period at the long-term USGS gaging stations. In some instances, snow may accumulate during November through March and cause runoff during the spring months. Snow falling during November through March also frequently melts slowly and infiltrates into the ground, or it may be lost to evaporation or sublimation.

During dry years, perhaps once or twice in each ten-year period, it is predicted that no naturally-occurring runoff would flow in RFP streams. Therefore, the monthly distribution discussed previously does not apply at these times. During wet years the monthly distribution presented previously for average runoff years may not be a good predictor of monthly flows. The estimated monthly distribution of water yield, discussed previously, applies to mean-annual conditions and would be expected to change for any given year.

Table 5
Estimates of Monthly Yield

	MONTHLY YIELD, ac-ft											
STREAM % Annual Yield	Jan 1	Feb 1	Mar 4	Apr 5	May 16	Jun 24	Jul 20	Aug 20	Sep 6	Oct 1	Nov 1	Dec 1
Woman Ck.	0.3	0.3	1.3	1.6	5.1	7.7	6.4	6.4	1.9	0.3	0.3	0.3
Walnut Ck.	0.3	0.3	1.4	1.7	5.5	8.3	6.9	6.9	2.1	0.3	0.3	0.3
S.Walnut Ck.	0.1	0.1	0.4	0.5	1.5	2.3	1.9	1.9	0.6	0.1	0.1	0.1
N.Walnut Ck.	0.2	0.2	0.9	1.1	3.6	5.5	4.5	4.5	1.4	0.2	0.2	0.2

NOTES:

Estimates given for Woman and Walnut Creeks at Indiana Avenue.
Estimates for North and South Walnut Creeks are at their confluence.

3.0 WATER QUALITY

The quality of water leaving the RFP and the quantity of certain chemical and radiochemical constituents being transported by the surface water is important because of the currently applicable site-specific stream standards applied to Walnut and Woman Creeks by the State of Colorado (Appendix E, Table E-2). The total quantity of a chemical or radiochemical constituent transported by a stream over a specific period of time, or the loading of that constituent, is determined by multiplying the concentration of the constituent by the total volume of flow.

Water samples have been collected at numerous RFP stream sites in 1989 and 1990 (Woodward-Clyde, 1990). Appendix E, Table E-1, presents analyses of water samples collected from 10 of these sites, a description of which follows:

SW-001 - Woman Creek at Indiana Avenue,
SW-002 - Woman Creek Diversion Ditch at Indiana Avenue,
SW-003 - Walnut Creek at Indiana Avenue,
SW-004 - Rock Creek Tributary north of RFP at Jefferson County line,
SW-007 - North Walnut Creek/Upper Church Ditch west of RFP,
SW-016 - North Walnut Creek between reservoirs A-3 and A-4,
SW-025 - South Walnut Creek between reservoirs B-4 and B-5,
SW-081 - North Walnut Creek/McKay Ditch west of RFP,
SW-104 - Woman Creek Tributary south of RFP, and
SW-107 - Woman Creek/Kinnear Ditch west of RFP.

Locations of these sampling sites are shown on Figure 1. Water-quality constituents tabulated in Appendix E, which were selected for a preliminary analysis of constituent loadings, include total dissolved solids (TDS), beryllium, copper, lead, plutonium-239, americium-241, various uranium isotopes, gross alpha and beta, and tritium. These variables were selected because they are indicators of possible contamination, they are potentially toxic, or they are judged to be of general concern to downstream users.

Four of the ten surface-water sampling sites previously described were selected for analysis of chemical and radiochemical constituent loading. Sample analyses for the other five sites are presented in Appendix E, Table E-1 for comparison purposes. The four sites selected for chemical and radiochemical constituent loading analysis are SW-001, SW-003, SW-016, and SW-025, all of which are located downstream from most of the developed areas at the RFP (Figure 1). Data for site SW-002, also representative of flow in Woman Creek at Indiana Avenue, was not used in the chemical-constituent loading analysis because of limited data at that site compared to the greater amount of data available at site SW-001. Also, it should be noted that runoff from the developed areas of the RFP which are in the Woman Creek watershed is prevented from entering the Kinnear Ditch or Woman Creek by the South Interceptor Ditch. That runoff is routed to Pond C-2 and is not released downstream. Except for that intercepted runoff, any increased loading due to runoff from the developed areas of the RFP should be reflected in the sample-analysis results. Also, analyses of samples collected from these sites are representative of the quality of water currently leaving the RFP. It should be noted that none of the concentrations of chemical or radiochemical constituents reported for sites SW-001, SW-003, SW-016, and SW-025 exceed the Colorado stream-segment standards for Walnut and Woman Creeks (Table E-2, Appendix E).

Representative average values of each of the selected constituents at each of the selected surface-water sampling sites were determined from the available analyses presented in Table E-1, Appendix E. These values constitute simple averages and are not discharge-weighted; that is, they are selected as representative of the available data, and are not selected as representative of either base-flow or flood-flow conditions. Those values were then multiplied by the average annual yield values estimated in Section 2.3.1 of this report, with appropriate units conversion factors applied, to yield estimates of average annual loadings. Table 6 summarizes the results of this analysis.

Once or twice every ten years, it is estimated that no naturally- occurring runoff will flow in Walnut Creek and Woman Creek (see Section 2.3.1 in this report). Therefore, in dry years, no loading of chemical or radiochemical constituents is expected from naturally-occurring runoff from the RFP. If water is diverted from Coal Creek via the Kinnear Ditch through the RFP during these dry years, then chemical loading to downstream users and reservoirs may well occur. The amount of loading will depend mainly on the quality of the water diverted.

Based on the analysis described previously, it also has been estimated that approximately once every ten years, naturally-occurring runoff in Woman Creek and Walnut Creek will exceed the average annual yield by a factor of about four times. If the average concentrations of chemical and radiochemical constituents in the runoff during these wet years are assumed to be approximately equal to those that occur in the average runoff years, then the loading of these constituents can also be expected to increase by a factor of four. This reasoning yields conservative, that is worst-case, results, because streamflow from large runoff events generally contains lower concentrations of chemical constituents, especially those not associated with suspended sediment. Although chemical-constituent concentrations might well increase substantially during a runoff event due to increased streamflow, concentrations of those constituents may be diluted. Estimates of wet-year loads, assuming chemical and radiochemical constituent concentrations remain unchanged, are presented on Table 6.

Annual loads of chemical and radiochemical constituents are not expected to be evenly distributed throughout the year in ephemeral streams like those on the RFP. Rather, the loading will occur predominantly during storm events. Data collected by ASI (1990f) and others in the Denver metropolitan area, and in other areas of the United States, have shown that up to 90 percent of the loading, especially from urban areas, may occur during a single large storm event (ASI, 1990c, Kunkel, 1988, Kunkel and Steele, 1989, and Mulhern and Steele, 1988).

Table 6
Results of Water-Quality Loading Analysis

STREAM SITE	WATER-QUALITY CONSTITUENT		CONCEN-TRATION	AVERAGE ANNUAL YIELD (ac-ft)	AVERAGE ANNUAL LOADING	WET-YEAR ANNUAL YIELD (ac-ft)	WET-YEAR ANNUAL LOADING
SW-1	TDS	(mg/l)	290	32.1	12.7 tons	128.4	50.7 tons
(Woman C.)	Beryllium	(mg/l)	0.005	32.1	0.4 lb	128.4	1.7 lb
	Copper	(mg/l)	0.025	32.1	2.2 lb	128.4	8.7 lb
	Lead	(mg/l)	0.005	32.1	0.4 lb	128.4	1.7 lb
	Plutonium-239	(pCi/l)	--	32.1	--	128.4	--
	Americium-241	(pCi/l)	--	32.1	--	128.4	--
	Uranium-233/234	(pCi/l)	1.1	32.1	$4.4x10^7$ pCi	128.4	$1.7x10^8$ pCi
	Uranium-235	(pCi/l)	--	32.1	--	128.4	--
	Uranium-238	(pCi/l)	0.6	32.1	$2.4x10^7$ pCi	128.4	$9.5x10^7$ pCi
	Gross Alpha	(pCi/l)	1	32.1	$4.0x10^7$ pCi	128.4	$1.6x10^8$ pCi
	Gross Beta	(pCi/l)	4	32.1	$1.6x10^8$ pCi	128.4	$6.3x10^8$ pCi
	Tritium	(pCi/l)	20	32.1	$7.9x10^8$ pCi	128.4	$3.2x10^9$ pCi
SW-3	TDS	(mg/l)	225	34.5	10.6 tons	138	42.2 tons
(Walnut C.)	Beryllium	(mg/l)	0.005	34.5	0.5 lb	138	1.9 lb
	Copper	(mg/l)	0.025	34.5	2.4 lb	138	9.4 lb
	Lead	(mg/l)	0.005	34.5	0.4 lb	138	1.9 lb
	Plutonium-239	(pCi/l)	0.01	34.5	$4.3x10^5$ pCi	138	$1.7x10^6$ pCi
	Americium-241	(pCi/l)	0.003	34.5	$1.3x10^5$ pCi	138	$5.1x10^5$ pCi
	Uranium-233/234	(pCi/l)	1.9	34.5	$8.1x10^7$ pCi	138	$3.2x10^8$ pCi
	Uranium-235	(pCi/l)	0.3	34.5	$1.3x10^7$ pCi	138	$5.1x10^7$ pCi
	Uranium-238	(pCi/l)	2.0	34.5	$8.5x10^7$ pCi	138	$3.4x10^8$ pCi
	Gross Alpha	(pCi/l)	4	34.5	$1.7x10^8$ pCi	138	$6.8x10^8$ pCi
	Gross Beta	(pCi/l)	6	34.5	$2.6x10^8$ pCi	138	$1.0x10^9$ pCi
	Tritium	(pCi/l)	40	34.5	$1.7x10^9$ pCi	138	$6.8x10^9$ pCi
SW-16	TDS	(mg/l)	350	22.7	10.8 tons	90.8	43.2 tons
(N. Walnut	Beryllium	(mg/l)	0.004	22.7	0.2 lb	90.8	1.0 lb
Creek)	Copper	(mg/l)	0.03	22.7	1.9 lb	90.8	7.4 lb
	Lead	(mg/l)	0.004	22.7	0.2 lb	90.8	1.0 lb
	Plutonium-239	(pCi/l)	0.01	22.7	$2.8x10^5$ pCi	90.8	$1.1x10^6$ pCi
	Americium-241	(pCi/l)	0.025	22.7	$7.0x10^5$ pCi	90.8	$2.8x10^6$ pCi
	Uranium-233/234	(pCi/l)	2.4	22.7	$6.7x10^7$ pCi	90.8	$2.7x10^8$ pCi
	Uranium-235	(pCi/l)	0.15	22.7	$4.2x10^6$ pCi	90.8	$1.7x10^7$ pCi
	Uranium-238	(pCi/l)	3.6	22.7	$1.0x10^8$ pCi	90.8	$4.0x10^8$ pCi
	Gross Alpha	(pCi/l)	4	22.7	$1.1x10^8$ pCi	90.8	$4.5x10^8$ pCi
	Gross Beta	(pCi/l)	12	22.7	$3.4x10^8$ pCi	90.8	$1.3x10^9$ pCi
	Tritium	(pCi/l)	80	22.7	$2.2x10^9$ pCi	90.8	$9.0x10^9$ pCi

Table 6
Results of Water-Quality Loading Analysis
(continued)

STREAM SITE	WATER-QUALITY CONSTITUENT		CONCEN-TRATION	AVERAGE ANNUAL YIELD (ac-ft)	AVERAGE ANNUAL LOADING	WET-YEAR ANNUAL YIELD (ac-ft)	WET-YEAR ANNUAL LOADING
SW-25	TDS	(mg/l)	260	9.5	3.4 tons	38	13.4 tons
(S. Walnut	Beryllium	(mg/l)	--	9.5	--	38	--
Creek)	Copper	(mg/l)	--	9.5	--	38	--
	Lead	(mg/l)	--	9.5	--	38	--
	Plutonium-239	(pCi/l)	0.05	9.5	5.9×10^4 pCi	38	2.3×10^6 pCi
	Americium-241	(pCi/l)	0.01	9.5	1.2×10^4 pCi	38	4.7×10^5 pCi
	Uranium-233/234	(pCi/l)	1.8	9.5	2.1×10^6 pCi	38	8.4×10^7 pCi
	Uranium-235	(pCi/l)	--	9.5	--	38	--
	Uranium-238	(pCi/l)	1.5	9.5	1.8×10^6 pCi	38	7.0×10^7 pCi
	Gross Alpha	(pCi/l)	6	9.5	7.0×10^6 pCi	38	2.8×10^8 pCi
	Gross Beta	(pCi/l)	9	9.5	1.1×10^7 pCi	38	4.2×10^8 pCi
	Tritium	(pCi/l)	0.04	9.5	4.7×10^4 pCi	38	1.9×10^6 pCi

NOTES:
-- no information available
Concentrations determined from values given in Appendix E, Table E-1.

4.0 ACKNOWLEDGEMENTS

This report was prepared under the direction of Michael G. Waltermire, P.E., Project Manager, of Advanced Sciences, Inc. (ASI). Mr. Stephen J. Playton, P.H., subconsultant to ASI, prepared this report, and it was reviewed by Dr. James R. Kunkel, P.E., P.H., Senior Hydrologist, ASI, and by Dr. Timothy D. Steele, P.H., Group Director, Physical Sciences, ASI. This report is submitted in partial fulfillment of the Zero-Offsite Water-Discharge study being conducted by ASI on behalf of EG&G, Rocky Flats Plant, Inc. EG&G's Project Engineer was R. A. Applehans of EG&G, Facilities Engineering, Plant Civil/Structural Engineering.

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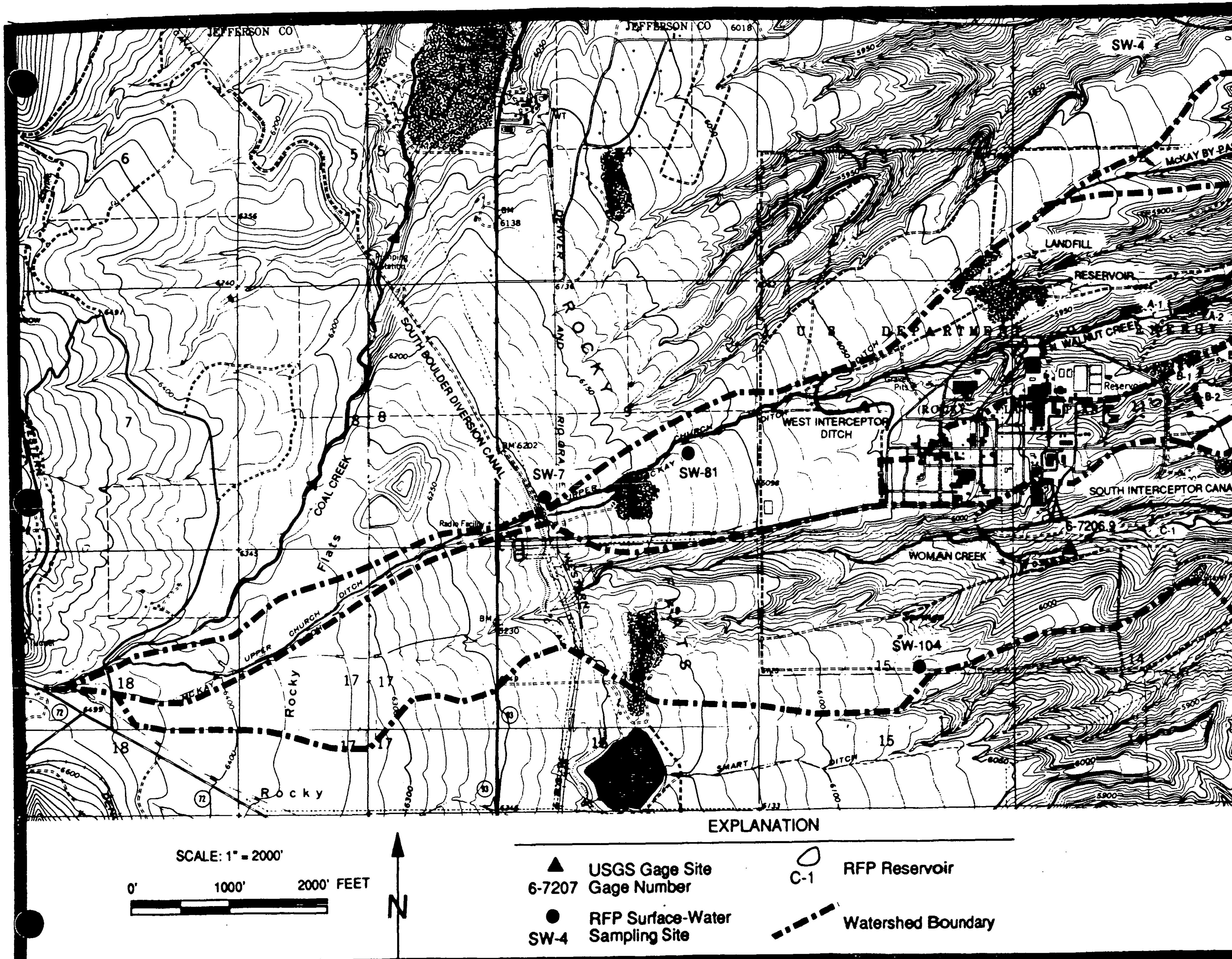


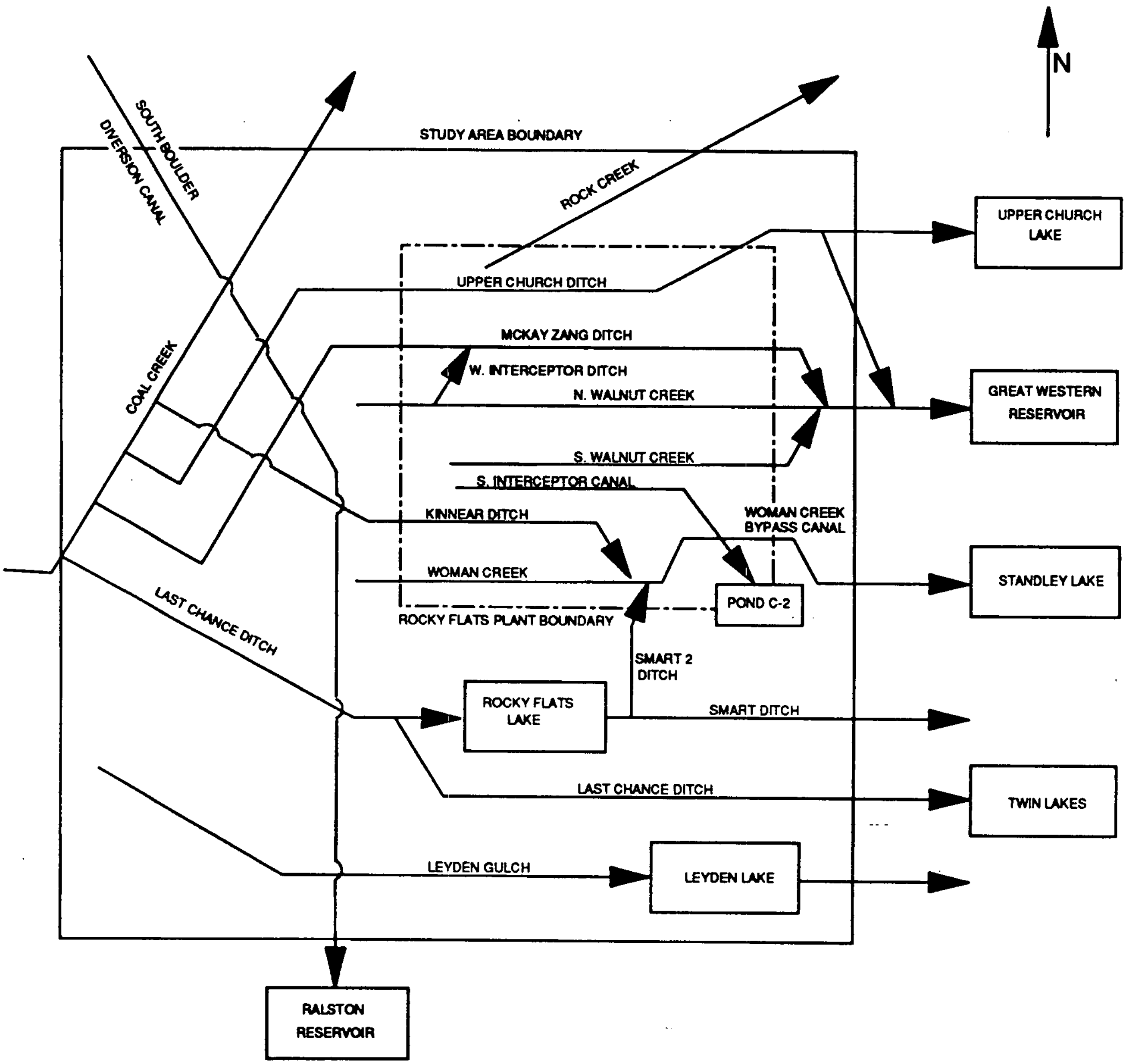
LOCATION OF STREAMS AND IRRIGATION DITCHES

WATER-YIELD AND WATER-QUALITY OF WALNUT AND WOMAN CREEK WATERSHEDS

ZERO-OFFSITE WATER-DISCHARGE

PROJECT 208.0104

FIGURE 1



ADAPTED FROM HURR (1976).

SCHEMATIC DIAGRAM OF SURFACE-WATER SYSTEM

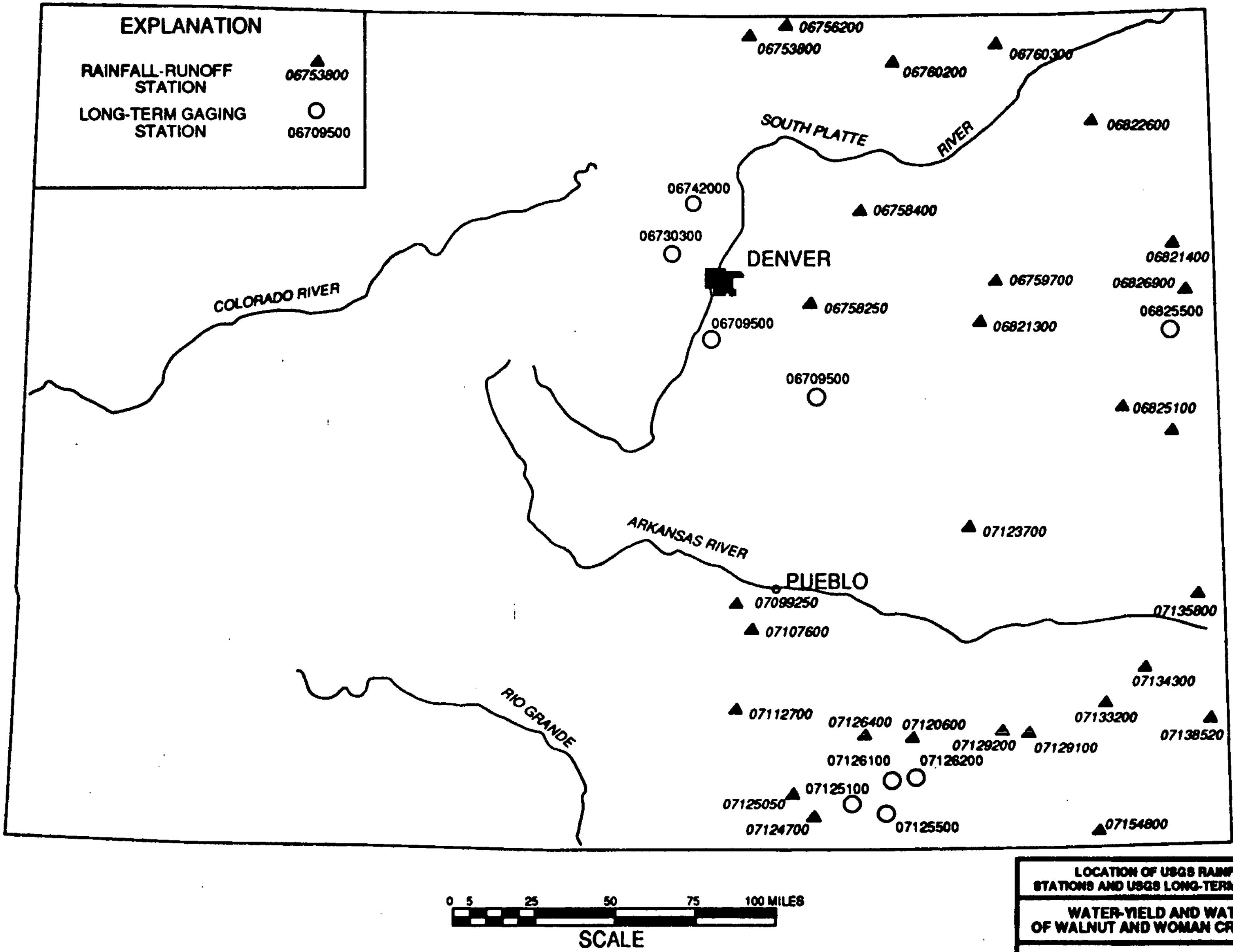
WATER-YIELD AND WATER-QUALITY OF WALNUT AND WOMAN CREEK WATERSHEDS

ZERO-OFFSITE WATER-DISCHARGE

PROJECT 208.0104

FIGURE 2

SURFSYS.DRW



LOCATION OF USGS RAINFALL-RUNOFF STATIONS AND USGS LONG-TERM GAGING STATIONS

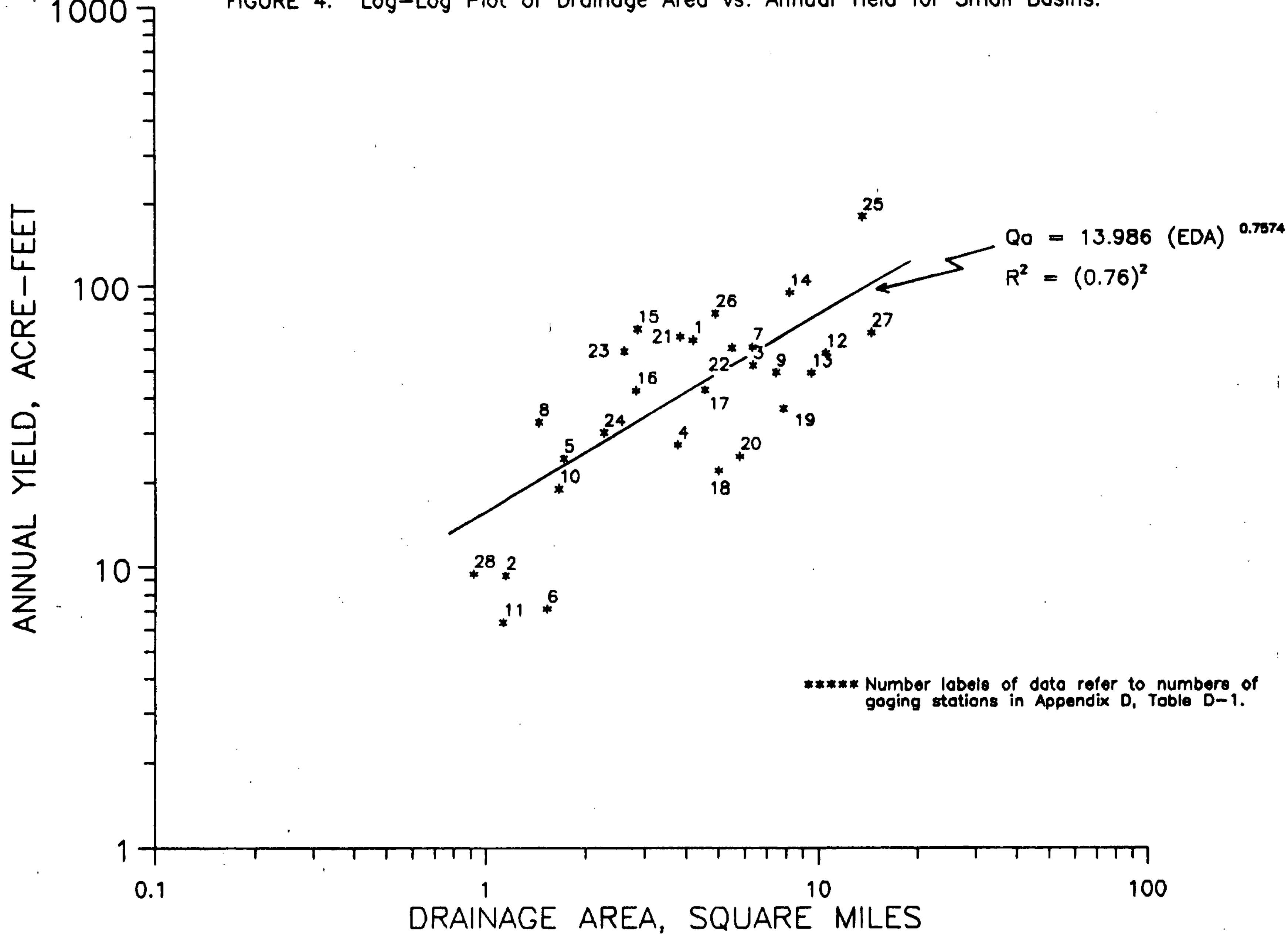
WATER-YIELD AND WATER-QUALITY OF WALNUT AND WOMAN CREEK WATERSHEDS

ZERO-OFFSITE WATER-DISCHARGE

PROJECT 208.0104

FIGURE 3

FIGURE 4. Log–Log Plot of Drainage Area vs. Annual Yield for Small Basins.



APPENDIX A

DEFINITION OF TERMS

DEFINITION OF TERMS

Total Drainage Area	Total topographic drainage area of the watershed.
Effective Drainage Area	Contributing drainage area for more frequent floods. Calculated by subtracting drainage areas for all erosion-control or flood-retention structures in the basin from the total drainage area.
Elevation	Altitude above sea level of the study site (gage site or point where dependent variables are to be estimated).
Elevation Factor	Altitude minus 2,600 feet (Livingston and Minges, 1987).
Relief	Altitude difference between the highest point in the effective drainage area and the gage or study site.
Relief Factor	Relief minus 18 feet (Livingston and Minges, 1987).
Channel Slope	Average slope of the main channel, computed by dividing the difference of the channel elevation at points 10 percent and 85 percent of the length of the main channel from the gage or study site by the channel length between those points.
Watershed Slope	Average slope of the watershed within the effective drainage area. Obtained by measuring lengths in miles of all 100-feet contour lines, multiplying by 100 feet, and dividing the resultant product by the effective drainage area.
Mean Annual Precipitation	Average annual precipitation at the gage or study site from 1951 through 1980, taken from isohyetal map compiled by Colorado Climate Center, Dept. of Atmospheric Science, Colorado State University, prepared by U.S. Geological Survey.
Correlation Coefficient	An estimator, ranging from -1 to +1, of the degree of association or correlation of two variables. A large positive or negative value indicates a high degree of association, and a value at or near zero indicates little or no association.
Standard Error of Estimate	The standard deviation of the distribution (assumed to be normal) of residuals about the regression line. Thus, approximately two-thirds of data values fall within the standard error of estimate (SE). For linear relationships, SE is expressed in the same units as the dependent variable; however, the SE of a regression having a logarithmic dependent variable is a constant percentage of the curve value throughout the range of the dependent variable.
Regression Analysis	The mathematical process of defining a dependent variable as a function of one or more independent variables. Regression analysis provides equations for estimating individual values of one variable from given values of the other.

APPENDIX B

USGS STREAM-GAGING DATA FOR RFP STREAMS

USGS STREAM-GAGING DATA FOR RFP STREAMS

Discharge, ac-ft

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
06720690 Woman Creek near Plainview												
1973										10	8.1	7.4
1974	5.4	13	17	31	24	23	53	46	26	18	18	18
1975	19											
06720700 Woman Creek at Rocky Flats Plant												
1972											2.2	10
1973	11	29	26	37	50	67	1020	709				
06720780 Walnut Creek at Rocky Flats Plant												
1972									11	0	10	8.7
1973	0.5	1.8	2.9	13	15	41	232	175	1.8	1.2	0	2.2
1974	3.9	2.3	16	53	37	92					0	0
1975	0											
06720790 South Walnut Creek at Rocky Flats Plant												
1972										22	18	24
1973	13	21	17	20	16	22	48	193	24	16	8.2	19
1974	16	10	18	19	12	18	25	9.7	9.6	1.4	2.2	2.1

APPENDIX C

STATE ENGINEER DITCH DIVERSION DATA

STATE ENGINEER DITCH DIVERSION DATA

YEAR	ANNUAL DITCH DIVERSION, AC-FT UPPER CHURCH DITCH	KINNEAR DITCH	MCKAY (ZANG) DITCH
1950	166	0	- -
1951	270	1000	- -
1952	160	1000	- -
1953	140	1000	- -
1954	0	0	- -
1955	20	20	- -
1956	0	0	- -
1957	0	1000	- -
1958	@	@	- -
1959	328	1694	0
1960	410	1327	0
1961	432	1784	202
1962	186	1610	0
1963	@	@	0
1964	0	@	*
1965	0	@	*
1966	0	0	0
1967	0	330	0
1968	0	0	0
1969	@	@	*
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	*	*
1975	*	*	@
1976	0	469	0
1977	0	214	0
1978	0	271	0
1979	*	1327	*
1980	0	1190	*
1981	0	*	*
1982	0	0	*
1983	0	*	*
1984	*	@	*
1985	0	125	*
1986	0	994	*
1987	0	145	*
1988	0	817	276

NOTES:

@ = records state water used or diverted to storage, but quantity unspecified.
* = no information available.

State Engineer Water Year, November 1 through October 31.

APPENDIX D

WATER-YIELD ANALYSIS DATA

Table D-1
Annual-Yield Stream-Gaging Station Information

	USGS Number		Effective Drainage Area (sq mi)	Elevation Factor (ft)	Relief Factor (ft)	Channel Slope (ft/mi)	Water-shed Slope (ft/mi)	Mean Annual Precip. (in)
(1)	06753800	Owl C. Trib. nr Rockport	4.22	2960	330	82	503	13.5
(2)	06756200	Geary C. Trib. nr Rockport	1.15	3020	330	113	935	14
(3)	06758250	Kiowa C. Trib. nr Bennett	6.40	3120	400	65	342	14.5
(4)	06758400	Goose C. nr Hoyt	3.79	2230	200	50	159	13
(5)	06759700	Sand C. Trib. nr Lindon	1.72	2320	150	38	277	15
(6)	06760200	Igo C. Trib. nr Keota	1.53	2410	420	86	375	13.5
(7)	06760300	Darby C. nr Buchanan	6.38	1790	260	59	515	12.5
(8)	06821300	N.F. Arikaree R. Trib. nr Shaw	1.45	2620	110	18	272	15
(9)	06821400	N.F. Black Wolf C. nr Vernon	7.51	1080	270	43	357	17
(10)	06822600	Patent C. nr St. Petersburg	1.66	1590	80	22	105	16.5
(11)	06825100	Landsman C. Trib. nr Stratton	1.13	1970	90	21	193	14
(12)	06826900	Sand C. nr Hale	10.60	1150	190	44	159	16.5
(13)	06857500	Big Timber C. Trib. nr Arapahoe	9.57	1540	270	28	162	14
(14)	07099250	Soda C. nr Livesey	8.25	2680	910	121	386	14
(15)	07107600	St. Charles R Trib nr Goodpasture	2.87	2630	600	111	512	14
(16)	07112700	Butte C. nr Delcarbon	2.84	3630	490	115	368	15
(17)	07120600	Timpas C. Trib. nr Thatcher	4.59	2740	470	78	317	12
(18)	07123700	Mustang C. nr Karval	5.04	2190	310	54	123	12.5
(19)	07124700	Gray C. nr Engleville	7.90	3580	3450	390	1050	15
(20)	07125050	Tingley Canyon C. nr Ludlow	5.83	3620	1240	177	908	14.5
(21)	07126400	Red Rock Canyon C. nr Bloom	3.86	2310	540	96	167	12.5
(22)	07129100	Rule C. nr Ninaview	5.54	2000	600	68	547	13.5
(23)	07129200	Muddy C. Trib. nr Ninaview	2.62	2030	420	90	764	13.5
(24)	07133200	Clay C. Trib. nr Deora	2.27	1680	280	81	194	14

Table D-1
Annual-Yield Stream-Gaging Station Information (continued)

	USGS Number	Effective Drainage Area (sq mi)	Elevation Factor (ft)	Relief Factor (ft)	Channel Slope (ft/mi)	Water-shed Slope (ft/mi)	Mean Annual Precip. (in)
(25)	07134300	Wolf C. nr Carlton					
		13.70	1260	450	37	185	14
(26)	07135800	Wild Horse C. Trib. nr Hartman					
		4.94	1190	260	38	100	15
(27)	07138520	Little Bear C. Trib. nr Lycan					
		14.60	1120	260	25	42	15
(28)	07154800	Cimarron R. Trib. nr Edler					
		0.92	1910	130	38	142	15

NOTE: Numbers in parentheses left of USGS numbers and names refer to data-point labels on Figure 2 in the main text.

Table D-2
Annual Runoff Data for Analyzed Stream-Gaging Stations

USGS Number and Name		Mean Seasonal Volume* (ac-ft)	Adjusted Annual Volume (ac-ft)	Range of Annual Volume (ac-ft)	Median Annual Volume (ac-ft)
06753800	Owl C. Trib. nr Rockport	63.8	68.9	0 - 274.2	7.2
06756200	Geary C. Trib. nr Rockport	9.3	10.0	0 - 30.7	9.1
06758250	Kiowa C. Trib. nr Bennett	51.9	56.1	0 - 202.8	28.0
06758400	Goose C. nr Hoyt	26.7	29.3	0 - 89.6	14.5
06759700	Sand C. Trib. nr Lindon	24.3	26.2	0 - 138.1	11.0
06760200	Igo C. Trib. nr Keota	7.1	7.6	0 - 38.0	1.7
06760300	Darby C. nr Buchanan	60.2	65.0	<1 - 208.4	36.8
06821300	N.F. Arikaree R. Trib. nr Shaw	32.7	35.3	0 - 161.5	28.7
06821400	N.F. Black Wolf C. nr Vernon	48.9	52.8	0 - 194.0	25.7
06822600	Patent C. nr St. Petersburg	18.9	20.5	0 - 132.3	4.3
06825100	Landsman C. Trib. nr Stratton	6.3	6.8	0 - 25.4	4.4
06826900	Sand C. nr Hale	57.2	61.8	1.8- 358.4	17.3
06857500	Big Timber C. Trib. nr Arapahoe	48.7	52.6	0 - 201.2	27.5
07099250	Soda C. nr Livesey	93.7	101.2	3.1- 472.9	66.4
07107600	St. Charles R Trib nr Goodpasture	69.7	75.3	9.0- 187.4	23.6
07112700	Butte C. nr Delcarbon	42.3	45.6	0 - 138.1	40.2
07120600	Timpas C. Trib. nr Thatcher	42.4	45.8	11.1- 91.6	48.0
07123700	Mustang C. nr Karval	22.0	23.8	0 - 100.0	11.7
07124700	Gray C. nr Engleville	36.3	39.2	0 - 229.3	22.0
07125050	Tingley Canyon C. nr Ludlow	24.7	26.7	0 - 88.9	20.8
07126400	Red Rock Canyon C. nr Bloom	65.4	70.7	0 - 249.8	53.0
07129100	Rule C. nr Ninaview	60.0	64.8	0 - 385.5	25.1
07129200	Muddy C. Trib. nr Ninaview	58.3	62.9	0 - 274.4	10.2
07133200	Clay C. Trib. nr Deora	30.0	32.4	0 - 138.9	19.4
07134300	Wolf C. nr Carlton	126.1	136.2	0 - 594.6	98.7
07135800	Wild Horse C. Trib. nr Hartman	79.0	85.3	0 - 246.8	80.9
07138520	Little Bear C. Trib. nr Lycan	67.4	72.8	0 - 254.9	85.1
07154800	Cimarron R. Trib. nr Edler	9.4	10.2	0 - 23.3	10.2

* - April through October

Table D-3
Stream-Gaging Stations Analyzed for Seasonal Distribution of Annual Yield

USGS Number		Gage Elevation (ft above MSL)	Drainage Area (sq mi)	Nov-Mar Yield as % of Annual Yield
06709500	Plum C. nr Louviers	5,585	302	20
06730300	Coal C. nr Plainview	6,540	15.1	10
06742000	L. Thompson R nr Berthoud	5,200	101	6
06758000	Kiowa C. at Elbert	6,800	28.6	12
06825500	Landsman C. nr Hale	3,720	268	15
07125100	Frijole C. nr Alfalfa	5,500	80	4
07125500	San Francisco C. nr Alfalfa	5,500	160	5.7
07126100	Luning Arroyo nr Model	5,150	86	4.6
07126200	Van Bremer Arroyo nr Model	4,960	168	5.1

STATION ID	MONTHLY YIELD AS A PERCENT OF ANNUAL YIELD											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
06709500	2	3	3	3	4	7	16	36	17	4	2	1
06730300	3	2	1	1	1	4	18	45	18	3	1	2
06742000	1	1	1	0	1	3	15	36	31	3	6	3
06758000	0	0	0	0	0	12	0	1	84	2	0	0
06825500	3	2	3	3	3	4	4	10	24	25	17	3
07125100	2	0	0	0	1	3	2	3	35	16	28	10
07125500	1	0	0	1	1	4	9	35	20	9	16	5
07126100	5	1	1	1	1	1	1	7	17	19	41	7
07126200	1	1	1	1	1	1	1	21	20	27	15	9
AVERAGE	2	1	1	1	1	4	7	22	30	12	14	5

Table D-4
Matrix of Correlation Coefficients of Independent-Variable Basin Characteristics

	Effective Drainage Area (EDA) (sq mi)	Elevation Factor (EF) (ft)	Relief Factor (RF) (ft)	Channel Slope (CS) (ft/mi)	Watershed Slope (WS) (ft/mi)	Mean Annual Precip. (MAP) (in)	Annual Yield (AY) (ac-ft)
EDA	1.00	-0.32	0.46	0.13	-0.12	0.01	0.76
EF		1.00	0.48	0.65	0.66	-0.34	-0.24
RF			1.00	0.89	0.59	-0.23	0.36
CS				1.00	0.73	-0.26	0.11
WS					1.00	-0.16	-0.04
MAP						1.00	-0.04
AY							1.00

Table D-5
Monthly Distribution of Runoff as a Percentage of Adjusted Annual Runoff at 28 Rainfall-Runoff Stations

USGS	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
06753800	Owl Creek Trib. nr Rockport	0						0	0	71	3	18	0	92
06756200	Geary Creek Trib. nr Rockport	0						0	0	19	54	19	0	92
06758250	Kiowa Creek Trib. nr Bennett	0						0	7	9	1	75	0	92
06758400	Goose Creek nr Hoyt	0						2	2	4	4	68	12	92
06759700	Sand Creek Trib. nr Lindon	0						0	0	31	3	55	3	92
06760200	Igo Creek Trib. nr Keota	0						0	0	23	42	10	17	92
06760300	Darby Creek nr Buchanan	0						0	15	11	26	35	5	92
06821300	North Fork Arikaree River Trib. nr Shaw	0						0	9	0	28	53	2	92
06821400	North Fork Black Wolf Creek nr Vernon	0						11	0	19	19	32	11	92
06822600	Patent Creek nr St. Petersburg	0						1	5	12	55	12	7	92
06825100	Landsman Creek Trib. nr Stratton	0						0	65	27	0	0	0	92
06826900	Sand Creek nr Hale	0						1	55	14	2	1	19	92
06857500	Big Timber Creek Trib. nr Arapahoe	0						0	0	58	14	15	5	92
07099250	Soda Creek nr Livesey	0						0	2	8	23	32	27	92
07107600	St. Charles River Trib. nr Goodpasture	0						0	1	3	41	44	3	92
07112700	Butte Creek nr Delcarbon	0						0	0	0	92	0	0	92
07120600	Timpas Creek Trib. nr Thatcher	5						0	9	6	50	10	12	92
07123700	Mustang Creek nr Karval	0						0	14	36	12	15	15	92
07124700	Gray Creek nr Engleville	0						0	0	2	74	16	0	92
07125050	Tingley Canyon Creek nr Ludlow	0						0	18	4	41	29	0	92
07126400	Red Rock Canyon Creek nr Bloom	0						0	0	0	30	48	14	92

Table D-5
Monthly Distribution of Runoff as a Percentage of Adjusted Annual Runoff at 28 Rainfall-Runoff Stations (continued)

USGS	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
07129100	Rule Creek nr Ninaview	0						0	4	0	21	67	0	92
07129200	Muddy Creek Trib. nr Ninaview	0						0	32	19	8	33	0	92
07133200	Clay Creek Trib. nr Deora	0						7	0	55	29	1	0	92
07134300	Wolf Creek nr Carlton	0						0	5	13	20	46	8	92
07135800	Wild Horse Creek Trib. nr Hartman	0						0	10	30	48	4	0	92
07138520	Little Bear Creek Trib. nr Lycan	0						1	13	31	1	33	13	92
07154800	Cimarron River Trib. nr Edler	0						14	31	3	4	22	18	92
AVERAGE FOR 28 RAINFALL-RUNOFF STATIONS (%)		0						3	10	18	27	28	7	92
AVERAGE FOR LONG-TERM STATIONS (%) (From Table D-3)		2	1	1	1	1	4	7	22	30	12	14	5	100
MONTHLY DISTRIB-UTION ESTIMATED FOR RFP STREAMS (%)		1	1	1	1	1	4	5	16	24	20	20	6	100
MONTHLY DISTRIB-UTION OF PRECIP-ITATION AT RFP (%)		7	5	3	3	4	8	11	19	11	9	8	11	100
RFP RAINFALL AVERAGE (in., 1953-76)		1.0	0.8	0.5	0.5	0.6	1.2	1.7	2.9	1.7	1.4	1.2	1.6	15.2

NOTE: Records not collected for 28 rainfall-runoff stations between November and

APPENDIX E

WATER-QUALITY INFORMATION

Table E-1
Water-Quality Analyses at Selected RFP Sampling Sites

SITE	DATE	TOTAL DIS-SOLVED SOLIDS (mg/l)	BERYL-LIUM (mg/l)	COPPER (mg/l)	LEAD (mg/l)	Pu-239 (pCi/l)	Am-241 (pCi/l)	U-233/234 (pCi/l)	U-235 (pCi/l)	U-238 (pCi/l)	GROSS ALPHA (pCi/l)	GROSS BETA (pCi/l)	TRITIUM (pCi/l)
SW-1	Mar 20, 89	--	0.005	0.0250	0.0250	--	--	--	--	--	--	--	--
	May 12, 89	--	0.005	0.0250	0.0050	0.00	0.0	1.1	0.0	0.6	<1	4	<20
	Jun 07, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Oct 23, 89	--	0.002	0.0363	0.0046	--	--	--	--	--	--	--	--
	Nov 07, 89	--	0.005	0.0250	0.0030	--	--	--	--	--	--	--	--
	Dec 15, 89	--	0.005	0.0250	0.0026	--	--	--	--	--	--	--	--
	Jan 23, 90	290	--	--	--	--	--	--	--	--	--	--	--
	Feb 21, 90	300	--	--	--	--	--	--	--	--	--	--	--
	Mar 16, 90	270	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
SW-2	Jun 07, 89	--	0.0050	0.0250	0.0050	0.06	0.01	1.8	0.0	2.0	11	9	230
	Jun 07, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
SW-3	Jun 26, 89	--	0.005	0.0250	0.0050	0.00	0	3.4	0.0	2.6	5	7	50
	Aug 18, 89	--	0.005	0.0250	0.0050	--	--	0.63	--	0.6	2	3	<0.09
	Aug 25, 89	--	0.005	0.00003	0.0050	--	--	--	--	--	--		
	Oct 03, 89	--	--	--	--	0.01	0.003	1.65	0.3	2.86	5.3	9.2	40
	Feb 12, 90	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Mar 17, 90	270	--	--	--	--	--	--	--	--	--	--	--
	*	180	--	--	--	--	--	--	--	--	--	--	--
SW-4	Mar 02, 89	180	0.005	0.0250	--	--	--	--	--	--	--	--	--
	Jun 15, 89	--	0.005	0.0250	--	0.00	0.000	1.10	0.0	1.1	2	4	<40
SW-7	Feb 27, 89	140	--	--	--	--	--	--	--	--	--	--	--
	May 31, 89	--	0.005	0.0250	0.0050	0.02	0.00	0.1	0.0	0.1	2	3	550
	May 31, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Jun 08, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Jun 08, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Aug 01, 89	--	0.005	0.0250	0.0050	0.00	0.00	0.2	0.0	0.1	1	8	<30
	Aug 01, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Jan 09, 90	--	0.002	0.0256	0.0030	--	--	--	--	--	--	--	--
	Mar 05, 90	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Mar 05, 90	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
SW-16	Jun 26, 89	360	--	--	--	0.01	0.000	2.30	0.0	3.2	4	10	110
	Jun 26, 89	--	--	--	--	0.00	0.040	2.50	0.2	3.4	6	16	<20
	Jul 17, 89	--	0.005	0.0250	0.0050	--	--	--	--	--	--	--	--
	Aug 10, 89	450	--	--	--	--	--	--	--	--	--	--	--
	Aug 25, 89	--	0.005	0.0250	0.0050	0.00	0.000	2.00	0.2	3.3	3	11	110
	Aug 25, 89	--	--	--	--	0.00	0.010	2.70	0.0	3.9	<1	12	150
	Sep 06, 89	350	--	--	--	0.01	--	2.90	0.1	3.6	--	--	80
	Oct 03, 89	--	0.002	0.0360	0.0020	0.02	0.026	1.92	0.15	4.08	3.3	11.9	<40
	Mar 17, 90	270	--	--	--	--	--	--	--	--	--	--	--
SW-25	*	260	--	--	--	0.05	<0.01	1.80	--	1.5	6	9	<0.04
SW-81	Jun 09, 89	--	0.0050	0.0250	0.0050	0.01	0.01	0.0	0.0	0.0	0	8	60
	Jun 09, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	0	--
SW-104	Jun 30, 88	248	0.005	0.025	0.005	0.00	--	0.333	--	0.593	4.47	10.5	0.00
	Jun 30, 88	--	--	--	--	0.00	--	0.356	--	0.0645	--	--	--
	Mar 02, 89	--	0.0050	0.0250	0.0185	--	--	--	--	--	--	--	--
	Mar 02, 89	--	0.0050	0.0250	0.1050	--	--	--	--	--	--	--	--
	Jun 01, 89	--	0.0050	0.0250	0.0050	0.08	0.01	0.5	0.0	0.3	78	58	110
	Jun 01, 89	--	0.0050	0.0250	0.0308	--	--	--	--	--	--	--	--
	Jun 16, 89	--	0.0050	0.0250	0.0845	0.19	0.06	0.4	0.0	0.7	66	88	250
	Jun 16, 89	--	0.0050	0.0333	0.0050	--	--	--	--	--	--	--	--
	Jul 14, 89	--	0.0050	0.0250	0.119	0.14	0.02	0.1	0.0	0.2	58	55	190
	Jul 14, 89	--	0.0050	0.0434	0.0050	--	--	--	--	--	--	--	--
	Aug 04, 89	--	0.0050	0.0510	0.153	--	--	--	--	--	--	--	--
	Aug 04, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Sep 19, 89	--	0.0050	0.0250	0.0050	0.005	0.095	0.20	<0.29	0.10	0.5	2.1	<170
	Sep 19, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Oct 13, 89	--	0.0050	0.0250	0.0050	0.003	--	0.52	0.22	0.59	0.9	0.3	<160
	Oct 13, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Nov 20, 89	--	0.0050	0.0250	0.0030	0.006	--	0.09	0.12	0.12	0.8	0.9	<30
	Nov 20, 89	--	0.0050	0.0250	0.0030	0.004	--	<0.12	0.09	0.09	0.1	1.7	980
	Dec 04, 89	--	0.0050	0.0250	0.0030	--	--	--	--	--	--	--	--

Table E-1
Water-Quality Analyses at Selected RFP Sampling Sites (continued)

SITE	DATE	TOTAL DISSOLVED SOLIDS (mg/l)	BERYLLIUM (mg/l)	COPPER (mg/l)	LEAD (mg/l)	Pu-239 (pCi/l)	Am-241 (pCi/l)	U-233/234 (pCi/l)	U-235 (pCi/l)	U-238 (pCi/l)	GROSS ALPHA (pCi/l)	GROSS BETA (pCi/l)	TRITIUM (pCi/l)
SW-104	Dec 04, 89	--	0.0050	0.0250	0.0030	--	--	--	--	--	--	--	--
(cont)	Jan 10, 90	--	0.0020	0.0200	0.0020	--	--	--	--	--	--	--	--
	Feb 05, 90	--	0.0021	0.0266	0.0570	--	--	--	--	--	--	--	--
SW-107	Feb 27, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Feb 27, 89	--	0.0050	0.0250	0.0055	--	--	--	--	--	--	--	--
	May 26, 89	--	0.0050	0.0250	0.0050	0.00	0.00	0.4	0.0	0.4	0	3	200
	May 26, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Jun 16, 89	--	0.0050	0.0250	0.0050	0.00	0.00	0.1	0.0	0.0	2	3	280
	Jun 16, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Jul 14, 89	--	0.0050	0.0250	0.0116	0.00	0.01	1.1	0.0	1.4	35	16	40
	Jul 14, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Sep 20, 89	--	--	--	--	0.020	0.277	0.54	0.08	0.38	0.4	3.0	220
	Nov 09, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Nov 09, 89	--	0.0050	0.0250	0.0050	--	--	--	--	--	--	--	--
	Dec 04, 89	--	0.0050	0.0250	0.0030	--	--	--	--	--	--	--	--
	Dec 04, 89	--	0.0050	0.0250	0.0030	--	--	--	--	--	--	--	--
	Jan 09, 90	--	0.0020	0.0200	0.0026	--	--	--	--	--	--	--	--
	Feb 05, 90	--	0.0020	0.0200	0.0020	--	--	--	--	--	--	--	--
	Mar 13, 90	170	--	--	--	--	--	--	--	--	--	--	--

NOTES:

* - no date given

! - SW-104, a seep, sometimes sampled under adverse and variable conditions. Analytical results subject to further validation.

Source of data - EG&G, Rocky Flats Plant, Inc.

Table E-2
Colorado Stream Standards for Walnut Creek and Woman Creek Segments

CONSTITUENT	(units)	SEGMENTS 4 & 5 WOMAN CREEK AQUATIC LIFE	AGRI-CULTURE	DRINKING WATER	SEGMENTS 4 & 5 WALNUT CREEK AQUATIC LIFE	AGRI-CULTURE	DRINKING WATER
TDS*	(mg/l)		500			500	
Beryllium*	(mg/l)	--	0.100	--	--	0.100	--
Copper	(mg/l)	@	0.200	1.000	@	0.200	1.000
Lead	(mg/l)	&	0.100	0.050	&	0.100	0.050
Plutonium-239	(pCi/l)	--	--	0.05+	--	--	0.05+
Americium-241	(pCi/l)	--	--	0.05+	--	--	0.05+
Uranium$	(pCi/l)	--	--	5+	--	--	10+
Gross Alpha	(pCi/l)	--	--	7+	--	--	11+
Gross Beta	(pCi/l)	--	--	5+	--	--	19+
Tritium	(pCi/l)	--	--	500+	--	--	500+

NOTES:

Segment 4 is defined as the mainstems and all tributaries to Woman and Walnut Creeks from sources to Standley Lake and Great Western Reservoir except for specific listings in Segment 5.

Segment 5 is defined as mainstems of North and South Walnut Creek, including all tributaries, lakes and reservoirs, from their sources to the outlet of ponds A-4, B-5 and C-2.

* - Standards not specifically given for Segments 4 & 5.

@ - acute hardness, limit = $1/2\ e^{(0.9422[\ln(\text{hardness})]-0.7703)}$
chronic hardness, limit = $e^{(0.8545[\ln(\text{hardness})]-1.465)}$

& - acute hardness, limit = $1/2\ e^{(1.6148[\ln(\text{hardness})]-2.1805}$
chronic hardness, limit = $e^{(1.417[\ln(\text{hardness})]-5.167}$

\+ - Standards not set based on water use.

$ - Limits not given for specific uranium isotopes.